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Regulating Electricity Spot Markets during Extreme Events: The 2021 Texas Case

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Abstract

This paper discusses the economic and legal challenges of price regulation in spot electricity markets during extreme events, taking the 2021 Texas winter storm as an example. The dual role of spot electricity prices (resource allocation and overall system reliability) in ERCOT's energy-only market resulted in allocating system reliability costs to load-shed consumers and spot electricity buyers, implying that complementary tools for covering system reliability costs should be sought. Further nuances are highlighted through a comparative qualitative analysis of value-of-lost-load pricing and anti-gouging legislation in the event context.

Keywords: *Value of Lost Load, Anti-Gouging Laws, Extreme Events, ERCOT, Electricity Spot Market Design, Price Regulation, System Reliability*

1. Introduction

Natural disasters and other extreme events can profoundly impact populations worldwide, inflicting severe damage to national economies both directly and indirectly (Panwar and Sen, 2019; Botzen et al., 2019). The interdependence between energy and other critical infrastructure makes ensuring reliable electricity supply critical, not only for timely relief efforts but also for avoiding positive feedback loops in infrastructure deterioration (Berariu et al., 2015; Lo Prete and Blumsack, 2023). However, the severity and damage scope of natural disasters can turn this into a challenging task. Of the most severe blackouts in the 50 years between 1965 and 2015, many resulted from natural causes, with hurricanes and windstorms alone accounting for almost a third (Rahman et al., 2016).

Disasters and extreme events can result in drastic scarcities and price spikes due to rapid shifts in demand and supply. Demand-related disruptions include surging demand for

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masks and sanitizers during the pandemic and rising demand for gasoline and essential goods before a hurricane strikes. In these cases, price spikes are driven by sudden shifts in the demand curve. Supply-related disruptions include property and infrastructure destruction, resulting in drops in the production and delivery of energy and other essential goods and services. In these cases, price spikes are driven by sudden shifts in the supply curve. Naturally, many extreme events result in both kinds of disruptions simultaneously. For instance, during the 2021 winter event, on which this article will focus, Texas had up to 50 GW of generation capacity unavailable[2] and up to 15 GW higher demand than was forecasted (Levin et al., 2022). Given the heterogeneous impact of such events over a region, different areas can experience different degrees of change in demand and supply. For instance, one area could be deprived of gasoline due to damaged roads or gas pipelines, while the neighboring area could experience no such problems; similar issues could arise in other markets, such as food or medicaments. In an ideal market, resulting conditions would be accurately communicated and resolved through adjusting prices; in practice, such communication can be thwarted to various degrees due to transaction and information costs, irrational pricing, various forms of government interference, and other factors. Identifying what, if any, are the remedies for these hindrances to efficient resource allocation requires an analysis of the decision-making processes through which said allocation is achieved. In this regard, electricity markets such as that of the Electric Reliability Council of Texas (ERCOT) contain certain features that require special attention. This article focuses on ERCOT's spot markets (day-ahead and real-time) that primarily reflect the drastic, rapid changes in demand and supply conditions, such as during extreme weather events or natural disasters.

The rest of the article is structured as follows. Section 2 discusses the general features of electricity spot markets that differentiate them from markets for other critical goods and services. Section 3 analyzes the 2021 Texas event, focusing on two regulatory tools: value-of-lost-load pricing and anti-gouging laws. Section 4 combines the analysis from the previous sections to highlight the legal and economic regulatory challenges resulting from decision-making processes in spot electricity markets.

[2] About 8 GWs of that capacity gap are outages that started prior to the event, such as planned outages; furthermore, the number reflects nameplate capacity, not to be confused with the (somewhat lower) foregone power generation by wind and solar plants (ERCOT 2021).

2. Spot Electricity Markets

Before discussing electricity markets, it is notable that electricity as a good[3] has qualities that differentiate it from other essential goods, such as food, medicine, or gasoline. First, storing electricity is very costly. Second, generation and consumption in the grid should always be closely matched due to its technical constraints (Kirchoff's circuit laws). Failure to do so can lead to the collapse of large parts of the grid, depriving significant shares of the population of electricity access for days or weeks. Such collapses can result from infrastructure damage from both human and natural causes; while the former tends to affect larger shares of the population, the latter has a much longer duration due to severe damages (Rahman et al., 2016).

The aforementioned condition of balancing electricity flow in the grid contributes to its highly varying value across space and time, as the amount of electricity supplied has to correspond to the momentaneous consumption in various locations of the power systems. As a result, while the value of electric energy is homogeneous with respect to its source (i.e., a kWh of electricity generated from wind power is indistinguishable from one generated by coal), it can vary based on location, time, and lead time between contract and delivery (Hirth et al., 2016). The first factor (location) is reflected through nodal and zonal pricing, while the other two (time and lead-time) are reflected through multiple market arrangements for electricity delivery, from long-term contracts to day-ahead and intraday to balancing markets. The idea is that these various arrangements would lead to a more optimal flow of electricity, better distribution of resources, and lower economic losses by better communicating the heterogeneity of costs and benefits across time and space.

The spot market is an "artificial" one - not naturally evolved but deliberately designed to mimic certain features of competitive markets within a highly constrained engineering system. Namely, the design of ERCOT’s spot electricity markets, with (1) merit order, (2) uniform clearing price, and (3) inframarginal rent, reflects the economic conception of a perfectly competitive market with (1) a marginal cost curve, (2) market equilibrium price, and (3) producer surplus, respectively. In a sense, this constitutes an inversion of the ordinary use of perfect competition in economic theory. Most markets are not perfectly competitive or efficient, and the concept of perfect competition is used as an analytical tool for studying market behavior rather than an accurate description thereof (Friedman, 1966). The theoretical conception of perfectly competitive markets, ordinarily used *to study* the spontaneous order that is characteristic of most free markets, is, in this case, used *to*

[3] Depending on state jurisdiction, electricity may be classified as either a good or a service.

construct a much more deliberate economic order within a highly constrained engineering system in an attempt to bring to its operation the advantages of free markets - competition, efficiency, and use of distributed knowledge. Though the aimed-for outcome in terms of price and quantity is the same in both cases, at the intersection of marginal cost (or merit order) and marginal benefit (or demand curve), the decision-making process is substantially different. While in naturally evolved markets the resulting price under ever-changing conditions is *discovered* by trial-and-error price alterations of individual suppliers, in spot electricity markets it is *determined* based on bids submitted by market participants in advance. The system operator collects the suppliers' bids for each predetermined interval and arranges them from lowest to highest, determining a single clearing price at the level required to cover forecasted demand.[4] In addition, the good or service itself has to be defined in advance instead of discovering what kinds of goods and services the market seeks under varying conditions. ERCOT's design is an energy-only market, where only actual generation is remunerated rather than available power capacity. Whether prices on such electricity markets incentivize sufficient investments into new capacities, including for such extreme events as in Texas, is debated in academic literature, and various market designs have been implemented and compared (see Cramton, 2017, for a general overview of market designs, and Sirin et al., 2023, for a review of academic literature from 2000-2022 on electricity price spike responses, as well as Papavasiliou, 2020; Sirin and Erten, 2022; and, most recently, Borenstein et al., 2023; Mallapragada et al., 2023; Petitet et al., 2023; Varawala et al., 2023).

Two practical challenges pertain. First is the reluctance of regulators to allow free price formation in periods of high scarcity due to concerns over market power abuse, which results in an imposition of a price cap that is arguably inefficiently low to incentivize sufficient investments (Joskow and Tirole, 2007). The challenge has been to set the price cap high enough to incentivize sufficient supply and investments for periods of high scarcity while simultaneously low enough to minimize market power abuse. Such a challenge is present in any market where price controls are introduced during an extreme event, risking to result in excess quantity demanded and lower quantity supplied, generating a persisting shortage. The second issue, more distinct for the electricity markets, is the presence of an externality due to the system's technical constraints (Jaffe and Felder, 1996). Given the system operator's aim to balance generation and consumption, the power plants that can provide additional capacity or flexibility to counterbalance unexpected shifts in consumption (or generation of other power plants) contribute to system resilience. Balancing and capacity

[4] This describes spot electricity markets with a uniform clearing price; pay-as-bid markets are not the main focus of this article.

markets and administrative scarcity pricing have been used to reward the positive externality that various power plants or storage technologies provide in terms of grid resilience (see Cramton, 2017, for a general overview). However, the same approach is not present regarding the negative externality imposed on the grid, especially on the consumer side: electricity markets generally *do not* internalize the cost of grid failure due to unbalanced consumption and generation (Gorman, 2022). That is, when an individual consumes more power than the system can handle, that particular consumer does not cover the total costs incurred by the resulting grid failure. Producers, though often held responsible for deviation from their projected supply and capacity, do not compensate for the total costs of a blackout that can occur due to their operational errors (Borenstein et al., 2023).

The combination of these two issues — the question of determining an adequate price cap and the absence of internalization mechanisms for the negative externality of grid failure — has led to the regulatory application of a metric called the value of lost load (VoLL). Laws explicitly aimed at preventing and penalizing price gouging are another option, though their application has mostly been to essential goods other than electricity. The two approaches will first be discussed separately below.

3. Electricity Price Regulation and the ERCOT Event

3.1. VoLL-Based Pricing During the Event

The technical features of the electric grid mean that the actions of an individual consumer or supplier can deprive the rest of grid electricity access, a non-pecuniary externality rarely present in other critical goods markets.[5] Moreover, this externality is not internalized, meaning that the option of engaging consumers' actual valuation of electricity through the price mechanism is not available; grid reliability is then treated as a public good, taking an *estimated* VoLL as a substitute for market valuation of electricity interruption costs (Gorman, 2022). VoLL, expressed as a monetary value per unit of electricity (e.g., $ per kWh or MWh), is consumers' willingness to pay for electricity that is not delivered due to supply disruptions or the economic cost of electricity supply interruptions, depending on which approach is taken to estimate it (Schröder and Kuckshinrichs, 2015).

By setting the price cap at the estimated VoLL level, regulators attempt to strike a balance between incentivizing supply and mitigating market power abuse; the idea is that an

[5] Another example is road infrastructure. If a traffic accident blocks the roads and raises the costs and time of transporting medicaments and food in the aftermath of a disaster, the person responsible for the accident is not required to compensate for these costs.

administratively imposed VoLL-based cap reflects the true economic value (i.e., the opportunity cost) of electricity to consumers. The issue is that when scarcity is at its highest, the scarcity price is set at a single estimated VoLL (Hogan, 2013), which then functions as the actual market price rather than simply as a cap. However, consumers' valuation of electricity during scarcity hours, just as during non-scarcity hours, is not homogenous. Not only do estimates of VoLL vary between and within consumer segments (e.g., Praktiknjo, 2016), but the willingness to pay can increase substantially depending on the outage duration (Praktiknjo, 2014; Gorman, 2022). Hence, maintaining prices at a fixed VoLL rate over prolonged periods risks resource misallocation, as the changes in underlying demand and supply conditions are no longer signaled through a price mechanism.

A case in point is the 2021 Texas winter event (see Borreson, 2022, for a timeline of the event), where frigid weather damaged power and gas infrastructure, resulting in a massive drop in available capacity with a higher than expected demand (Busby et al., 2021). In an attempt to prevent a complete system collapse, ERCOT initiated load shedding, which its pricing mechanisms interpreted as the presence of excess power capacity, leading to lower prices as a result (Baker and Coleman, 2022); the Public Utility Commission of Texas (PUC) then directly intervened to set the price at the high system-wide offer cap of $9,000/MWh (see Fig. 1 below). Several considerations drove its decision to utilize that benchmark. The Commission reasoned that low prices generated by ERCOT's faulty pricing algorithm were "inconsistent with the fundamental design of the ERCOT market. Energy prices should reflect scarcity of the supply. If customer load is being shed, scarcity is at its maximum, and the market price for the energy needed to serve that load should also be at its highest" (PUC, 2021). At the same time, the Commission was facing another concern because the peaker net margin threshold of $315,000/MW-year had already been crossed,[6] meaning that, under ordinary rules, the high system-wide offer cap would be suspended in favor of the low system-wide cap, determined as the greater of either $2,000/MWh or 50 times the natural gas price index value (PUC, 2021). Given the abnormally high natural gas prices during the event, the rule would have led to a low system-wide offer cap, ironically, *higher* than the high one. The Commission, therefore, ordered suspending the low system-wide offer cap due to concerns over protecting consumers, setting $9,000/MWh as the market price for four days and leaving it as the price cap in the aftermath, an order that was repealed only 16 days later (Baker and Coleman, 2022; Littlechild and Kiesling, 2021). In short, by ordering that load shedding be reflected through maximum prices while

[6] The peaker net margin, which "serves as a simplified measure of the annual net revenue of a hypothetical peaking unit," achieved more than double of its threshold value in February alone, reaching over $700,000 per MW-year (Potomac Economics, 2021).

simultaneously suspending the low system-wide offer cap, the Commission attempted to balance minimizing consumer risks and providing adequate prices to incentivize supply.

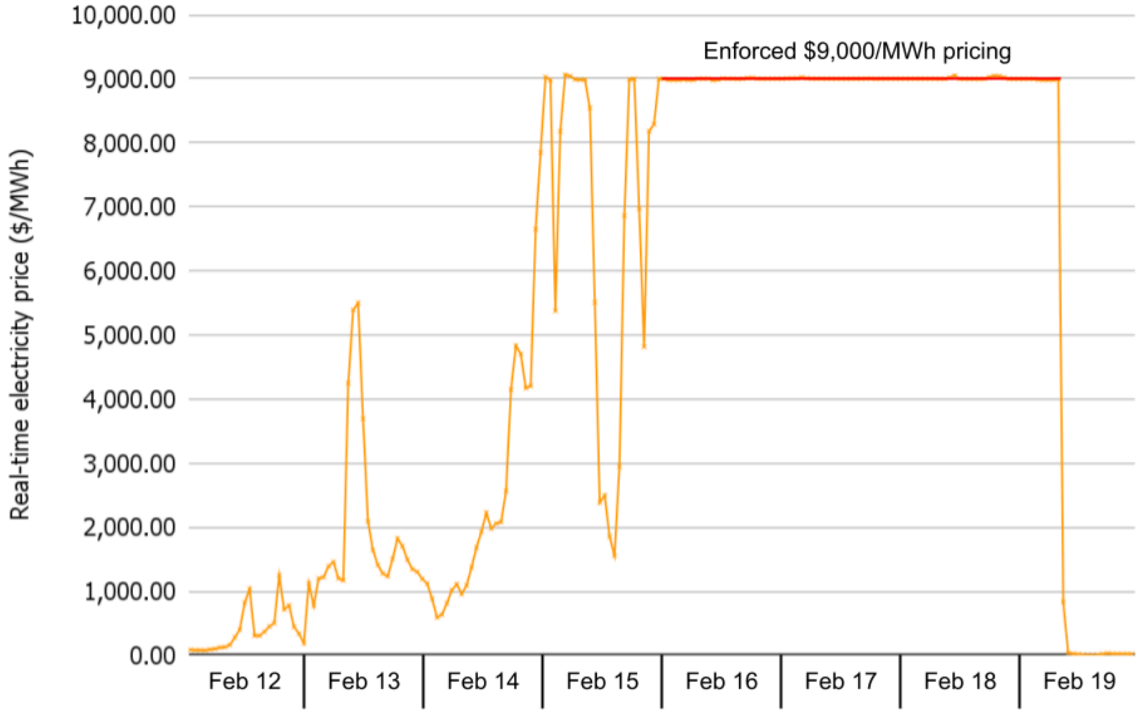

Fig. 1. ERCOT real-time market prices during the 2021 Texas event, averaged across settlement points on an hourly basis[7]

The prolonged maintenance of prices at such a high level has been argued as one of the main issues behind the inefficient system response, resulting in exorbitant consumer bills and economic inefficiency valuing billions of dollars (Littlechild and Kiesling, 2021; Busby et al., 2021). Prior to the PUC's order, the prices were as low as $1,200/MWh; the following 7.5-fold increase in prices did not incentivize sufficient supply to restore the load, not because the 50 GWs of power that were offline chose not to react to the higher price, but because additional supply was physically unavailable, mainly due to damaged infrastructure and limited interconnection capacity (Busby et al., 2021; Levin et al., 2022). At the same time, since only part of ongoing consumption was bought at spot prices and there was further hedging of prices between retailers and consumers, the ability to affect demand was substantially reduced. Accordingly, even if VoLL were an accurate estimate of marginal benefit for those whose load was lost, only part of the ongoing consumption would be valued as high as $9,000/MWh. However, all real-time electricity (and much of day-ahead) ended up

[7] Using historical data on real-time ERCOT prices from https://www.ercot.com/mktinfo/prices

being purchased at such high prices (either by consumers or retailers) despite much of it being utilized for far lower end-use values.

The whole ordeal with pricing may have started because the pricing algorithm was misled by load shedding, yet load shedding itself now meant that marginal benefits of electricity supply varied drastically across nodes, with some consumers powering desktop lights and others deprived of heating, a heterogeneity not incorporated in the PUC's centralized decision-making. The point is not to retrospectively blame the PUC but to recognize that the electricity markets may be more limited in their price signaling capabilities, the importance of which was highlighted by Hayek 80 years ago (Hayek, 1945). At the same time, as inefficient as such scarcity pricing was for resource allocation among consumers, it did convey another benefit for the system as a whole, as consumers or retailers purchasing electricity at spot markets paid high prices not just for electricity consumed but for the availability of grid power in the first place, for themselves as well as (by preventing a complete blackout) for the rest of the consumers. In an energy-only market such as ERCOT, system reliability costs were allocated between those purchasing electricity at spot prices and those whose load was shed under load-shedding conditions.

Aside from short-term supply adjustment, the other purpose of high prices is to incentivize capacity availability for similar extreme events in the future. In other words, power plants will be interested in investing in resilience and weatherization, given the expected high benefits they could reap. Incentivizing long-term supply was the purpose of the high system-wide cap in ERCOT; once the peaker margin threshold is achieved, a much lower price would have likely sufficed for short-term supply adjustments, something that the PUC perhaps had not realized (Littlechild and Kiesling, 2021). With regard to prices as signals for capacity additions for future extreme events, the difficulty is that such events are hard to predict and model by their very nature. Information uncertainty and lack of hedging reduce the likelihood of investments into resilience for low-probability, high-impact events by making it harder to predict future spot prices and translate them into current investments (Mays et al., 2022; Gruber et al., 2022), though the extent of this issue has been disputed (Biggar and Hesamzadeh, 2024). In either case, whether considering short-term or long-term effects on supply, the effectiveness of this approach would rely on more efficient communication of VoLL heterogeneity during the event. Using different rates of scarcity pricing for different parts of the grid has been suggested as one of the remedies for the Texas event (Littlechild and Kiesling, 2021). Norway and Italy, for instance, have used differing VoLLs based on consumer group, duration of the interruption, and the time of the blackout (Ovaere et al., 2019). As a result of general analysis and modeling, it has also been argued that using more detailed VoLL based on consumer segmentation and interruption times can lead to lower operational costs during high scarcity periods (Ovaere et al., 2019). While such an approach was no doubt used by ERCOT in its centralized load shedding decisions, shedding lower priority loads and maintaining the more critical ones connected to the extent that such flexibility is allowed by the feeders, having a more heterogeneous scarcity pricing scheme can similarly improve the efficiency of market participants' decentralized decision-making.

3.2. Anti-Gouging Legislation

The extremely high electricity expenditures that resulted from the ERCOT event led to the introduction of several electricity-related bills, including Senate Bill 680 (hereafter SB680), which would clarify electricity as a necessity during a declared disaster and make it subject to Texan anti-gouging laws. The bill proposed penalizing the sale of electricity "at an exorbitant or excessive price," as well as for demanding such a price in connection with its sale. The bill was ultimately rejected; an alternative, House Bill 16, was passed, prohibiting retailers from offering wholesale indexed electricity to residential and small commercial consumers (Litttlechild and Kiesling, 2021). Nonetheless, a discussion of the potential ramifications of SB680 in the subsequent section highlights the decision-making processes in spot electricity markets such as ERCOT, especially since one cannot preclude that a similar bill would be introduced in the future in Texas or elsewhere.

In periods of disaster or other extreme events, anti-gouging laws are not unique to the energy sector but have been applied to various essential goods. These laws are usually triggered upon emergency declaration and limit the price increase of essential goods compared to the pre-disaster level. The limit can be either absolute (allowing no increase), a few percentage points, or more vaguely defined as such that does not exceed an "unconscionable" act or present "exorbitant" prices (see Helveston, 2024 for a detailed survey of the anti-gouging laws in the US). Among energy products, such laws have typically applied to gasoline and similar fuels. Perhaps the most relevant difference between these fuels and electricity can be illustrated through the Wright et al. (2019) study, which showed that gasoline prices reacted days before the hurricanes and the enactment of anti-gouging laws. The relative ease with which residential and commercial consumers can store gasoline can result in its hoarding prior to the hurricane's strike, something that has been less attainable with electricity, given its storage costs.

A regulation functioning somewhat as an anti-gouging law was developed for the balancing market of Texas in 2003, following an event similar to the 2021 grid failure, both happening in February, characterized by freezing temperatures that resulted in scarcity of supply and unusually high prices, with concerns over price gouging. Back then, the clearing price at the balancing market had reached $990 per MWh and stayed at that level for an hour, roughly a 15-20-fold increase compared to the price levels of the week before (Hurlbut et al., 2004). In June of the same year, the PUC developed the Competitive Solution Method (CSM), an automatic mitigation procedure that tests every settlement interval for competitive sufficiency and, in case the test fails, applies a scarcity rent equivalent to 1.5 times the price that would have purchased 95 percent of the offer stack (Hurlbut et al., 2004). In other words, CSM is a variant of an anti-gouging law that can enforce price caps based not on the price increase over time but on a bidding curve at any given settlement interval. Similar regulations exist in other regional real-time markets, e.g., in PJM, where certain suppliers' prices can be limited to 110% of their costs if there is a substantial risk of market power abuse (Cramton, 2017).

4. Resulting Implications

Having discussed some general features of spot electricity markets, as well as the experience of ERCOT during the 2021 event in particular, this article now moves to the analytical section of the implications for price regulation. What follows is an analysis of how electricity markets (through the case of ERCOT) deal with resulting post-extreme-event conditions (generally shortages) and the implications for prices and price regulation.

4.1. Pricing in Shortages

As stated earlier, spot electricity markets aim to optimize pricing in a framework that mimics competitive, naturally evolved markets by equalizing marginal costs and marginal benefits of electricity via bidding curves. However, though the framework may be the same, the sequence of decision-making that ultimately leads to price formation is different, and so are the implications for price regulation.

Since no player has perfect knowledge and control of the situation at any given time, let alone under emergent post-disaster conditions, it is virtually inevitable that some errors will be made, and it will take the market some time to approximate equilibrium prices. In itself, higher post-disaster scarcity (due to infrastructure damage, surging demand, and other factors) does not *necessarily* result in shortages or surpluses; what generates them is the time and effort required of the market participants to adjust the prices and react to those prices accurately. Though such situations are not preferable to a market equilibrium, they are essential to *discovering* the equilibrium. A medical supplier may underestimate the demand for medicaments, while a food supplier may discover, upon bringing provisions, that residents had stored enough food in advance. Through trial and error, at the cost of short-term shortages and surpluses, market participants dynamically discover what the situation is like. One of the negative consequences of anti-gouging laws is the impediment to such signaling through prices. It is not that there is no risk of prices being "too high" due to abusive or irrational decision-making, but that it is harder to discover the optimal prices without being able to tell whether prices are, in fact, "too high," when the government prohibits raising them to high levels in the first place (Skarbek, 2008).

As electricity is continuously generated and consumed in real time, there is almost inevitably a delay between a drastic scarcity-generating impact (as the winter storm in Texas) and price adjustments (followed by price responsiveness). However, unlike other markets, spot electricity markets have a much lower tolerance for subsequent equilibrium discovery through trial and error since even relatively brief differences between generation and consumption in the grid risk blackouts and system collapse. Once voluntary load-shedding resources were exhausted, ERCOT engaged in involuntary shedding, surgically isolating shortages to keep the grid balanced. Instead of its central role in (post-disaster) equilibrium discovery through the transmission of decentralized information, the price mechanism, in this case, played a complementary role in ERCOT's centralized decision-making, yielding its purpose of efficient electricity resource allocation to that of more urgent system reliability, - a point the Supreme Court of Texas recognized in June 2024, overturning an earlier decision of the court of appeals and defending the PUC's actions of directly enforcing the price at high system-wide cap level, in circumvention of more "competitive" approaches (Supreme Court of Texas, 2024).[8] At the same time, despite the PUC's logic of scarcity prices having to be at their highest if the load is being shed (as noted in the quotation earlier on), prices were held at $9,000/MWh level through mid-morning of February 19, more than a day after last load shed instructions were recalled on midnight of February 17 (Potomac Economics, 2021). Whether this constitutes grounds for further litigation remains to be seen.

Inefficient price regulation differs in its detrimental effects based on the price mechanism's role in a given market. In markets where pricing decisions (including mistaken pricing) provide feedback mechanisms for discovering the optimal market prices in heterogeneously impacted areas, inefficient regulation can impede such communication, making it harder or even impossible to reach equilibrium, generating sustained shortages or

[8] Whether the PUC was wise in its particular decisions is a separate question which, as the state's Supreme Court argued, is outside the scope of judicial expertise.

surpluses. In ERCOT's case, where pricing was one of the tools for managing overall system stability, inefficient regulation results in maladjustments of relative benefits of system reliability and efficient resource allocation (in this case, the latter being sacrificed without corresponding benefits to the former). The misallocation, under shortage, is reflected in (1) still-connected consumers' ongoing consumption of lower-value electricity at a high cost, as well as (2) spot market purchasers and load shed consumers taking on the costs of grid reliability to avoid complete blackout, from which other consumers benefit as well. The dual goals of real-time resource allocation and system reliability are intertwined in a market designed for a single good ("energy-only market"), complicating decision-making in price regulation.[9] Similarly, Gorman (2022) differentiates between VoLL in the context of cost-benefit analysis for centralized decision-making on grid reliability and electricity rationing during shortage periods. The former "directly compete[s] with cost-effectiveness analysis where a central agency can choose a physical reliability objective (i.e., "one outage in ten years") rather than relying on uncertain VoLL estimates," while the latter "can be facilitated by decentralized self-sorting arrangements, such as dynamic pricing or demand-response programs, which only need a loose connection to VoLL estimation" (Gorman, 2022). However, it seems that the two are combined when ERCOT enforced VoLL-pricing, simultaneously serving as a rationing signal for market players and as an estimate of grid reliability benefit.

The differences between VoLL pricing and generic anti-gouging legislation utilized for other critical goods help further highlight nuances for price regulation on spot electricity markets. Two points of difference are worth highlighting:

1) *Enforcement of price regulation:* Spot electricity markets can directly enforce price regulation, as VoLL price caps or pricing are automatically enforced or activated in electricity markets. However, anti-gouging laws are applied through post-factum legal decisions, thus affecting the actual prices during the event based only on participants' expectations of the relationship between high prices and later repercussions.

2) *Aim of price regulation:* Though concerned over price gouging, the system operator's primary goal is to ensure system reliability. VoLL pricing is derived from an estimate of consumer benefit, its general goal being accurate scarcity signaling; it can also be used to incentivize supply, as the PUC did in Texas.

[9] This should not be taken as a prima facie argument that price regulation is simpler, or more efficient, in a system with separate capacity markets. The point is to highlight the underlying complexity of the electricity system and markets in general.

However, anti-gouging laws are purely supplier-focused and aim to prevent "exorbitant" price rises, regardless of whether those prices correspond to consumers' subjective product valuation.

Under this differentiation, a mechanism like CSM can be classified as a hybrid; its mode of enforcement is automatic as opposed to standard ex-post anti-gouging regulation, but its underlying aim is similarly based on determining "reasonable" prices based not on consumer's valuation, but on the cost curve, with the offer stack used as a proxy.

4.2. Enforcement of Price Regulation

Since electricity's real-time distribution is particularly critical, for the reasons outlined earlier, real-time enforcement of price regulation can have a significantly different effect than post-factum enforcement.

Since trade in electricity spot markets happens through a centralized platform, a relevant regulatory authority has no difficulty enforcing the VoLL cap or scarcity pricing.[10] The automatic enforcement of the VoLL cap or scarcity pricing allows to affect prices in periods of high scarcity directly. Whether this translates into desired adjustments in power output and consumption is a separate question that relies on additional factors, such as infrastructure resilience, demand elasticity, market design, and available grid management technologies; the ERCOT case illustrates that in the presence of unresponsive demand and unprepared infrastructure, price incentives may not fully produce the desired short-term results. In light of this, some complementary approaches have been suggested in economic and legal scholarship on the event, ranging from more incentive-oriented measures, e.g., removing the price cap (Biggar and Hesamzadeh, 2024), refined scarcity pricing and demand response mechanisms (Littlechild and Kiesling, 2021; Busby et al., 2021; Baker and Coleman, 2022; Levin et al., 2022; Hartley et al., 2023; Lo Prete and Blumsack, 2023; Madden, 2023; Biggar and Hesamzadeh, 2024), to more direct measures, e.g., firming (Borreson, 2022; Gruber et al., 2022) and mandatory forward contracting (Mays et al., 2022) obligations, interconnection expansion (Busby et al., 2021; Levin et al., 2022), to ERCOT administratively committing units during a scarcity event (Madden, 2023).

Anti-gouging laws affect consumption and generation based on the expectations of various actors as to what the legal decisions will be after the event. In particular, the

[10] This could change as separate microgrid markets emerge, especially since they may be the only options for electricity supply in certain cases (as damaged infrastructure prevents central grid transmission).

vagueness of wording in anti-gouging regulation, as in Texas, generates uncertainty that may be reduced over time as legal cases accumulate. From the generation side, peaker or other fuel-based power plants, which ordinarily set the clearing price in such events, may become reluctant to bid high prices. Insofar as these power plants fear being unable to win court cases even if their bids are raised justifiably to reflect costs, the result may be insufficient capacity to provide power under given circumstances. Furthermore, as consumers expect future compensation for what the court may determine as exorbitant pricing, their demand responsiveness may be reduced. While this general impact of an implicit price ceiling can be present for other goods, the structure of electricity markets makes them more susceptible to adverse effects. First, unlike a VoLL-price cap, anti-gouging laws do not provide immediate mechanisms for price control, an important factor when considering the rapidly changing conditions of demand and supply in electricity and the corresponding need for grid balancing. For this reason, regulations that prevent price gouging in electricity markets (examples given above for ERCOT and PJM) are enforced automatically in those markets. Second, standard anti-gouging legislation leaves the determination of an "exorbitant price" up to courts, not to market operating bodies, further reducing the ability to affect prices directly.

4.3. Aim of Price Regulation

The most significant difference between anti-gouging laws and VoLL-pricing stems from their underlying logic. The adoption of SB680 would have meant that ERCOT markets are subject to both regulatory constraints, yet the two have conflicting philosophies regarding price regulation. The VoLL methodology approaches the problem from the demand-side analysis, attempting to estimate the consumer’s willingness-to-pay curve; in theory, this should allow for drastic increases in prices as the value of essential goods (including electricity) increases during extreme events.

In contrast, anti-gouging laws focus on the supply side, i.e., whether the supplier has set a price that can be justified by the costs in the regulator's opinion. For instance, gas retailers in Idaho were forced to compensate for the excessive prices charged for gasoline during the pandemic; similarly, a fuel retailer in Kentucky had to pay a settlement to disgorge its profits made from higher prices after the Colonial Pipeline shutdown in 2011 (Helveston, 2024). Note that these sellers were found guilty of charging excessive prices despite consumers *knowingly purchasing* the product at said prices, indicating that their willingness to pay was at least equal to the price at the time. Such laws, therefore, ignore the subjective value of the product to consumers, and they can be applied more discriminatorily in electricity markets than VoLL caps. Since the value of electricity is homogeneous as to its source, VoLL-based price caps, even if they are more granulated as to time, space, and consumer segment, will be applied equally regardless of the source of electricity. In contrast, since the costs of generating electricity are heterogeneous as to the source, especially during extreme events such as winter storms (Michelfelder and Pilotte, 2022), anti-gouging laws, depending on their formulation, can penalize one supplier and not the other despite both of them selling, or even simply bidding, at the same price. The fact that price determination on spot markets happens by an actor other than the bidder and the seller of said electricity risks causing substantial misalignments in incentives and legal responsibility under standard anti-gouging laws.

Under major demand-driven disruptions, it is assumed that individuals could start stockpiling electricity in preparation for a hurricane or other foreseeable extreme event, resulting in a pre-disaster price spike due to the increased demand. In the case of a VoLL-set price cap, the spot prices reaching the cap would not reflect rising production costs, assuming that the infrastructure and fuel are still intact and readily available. From the viewpoint of its purpose, the cap's efficiency will depend on whether the consumers hoarding electricity are aware of the prices. Since most consumers are not responsive to real-time prices, the actual flow of electricity consumption would not be as affected. However, with the advent of smart grid technologies, real-time or peak pricing tariffs, and storage opportunities, there will be an increase in short-term demand elasticity, and more accurate VoLL application (should it still be applied) would become critical for proper grid management under extreme events.

The potential effects of standard anti-gouging laws during demand-related disruptions in electricity markets are relatively more detrimental than for similar demand-driven spikes under a VoLL cap and supply-driven disruptions in electricity markets. The supply-focused approach of anti-gouging laws that ignores consumer benefits means that the effective or expected price limit will be *lower* for electricity markets under demand-driven disruptions than supply-driven ones. If the rise in prices is due to a demand spike *prior* to the disaster but *after* the emergency declaration and the costs of power generation have not changed, then the anti-gouging laws, comparing prices prior to and after the emergency declaration, will find companies guilty of unjustifiably higher profits. Anti-gouging laws, as proposed by SB680 in Texas, would prohibit both the sale of electricity at an exorbitant or excessive price and simply demanding such a price in connection to its sale. Ordinarily, a company will not bid (i.e., "demand") lower prices than the ones at which it may sell. *However, the design of single clearing price electricity markets often reverses this situation.* A solar power plant may bid a very low price during an emergency but will often sell at a much higher price, the clearing price, determined by a marginal natural gas generator or the VoLL cap. In the absence of a clear legal distinction between bidding and price-setting parties in such regulations, an anti-gouging law could, therefore, risk disincentivizing the engagement of solutions for extreme events with low marginal costs of generation (e.g., storage, nuclear power).

4.4. Recommendations

A case study highlights the potential deficiencies of a system; coming up with solutions is more challenging without foresight and counterfactuals. On the surface level, those who have analyzed the 2021 Texas winter event agree that low system resilience was a central issue, which, among other consequences, led to an ineffective application of the scarcity pricing mechanism on ERCOT's spot market during the event. On a deeper level, there is a diversity of opinions on the best way to improve system resilience and ensure adequate pricing. This article limited its focus to issues of price regulation during the event (that is, once the shortage had occurred) and did not address the broader comparison with other market designs or activities, such as weatherization mandates and resilience enhancement. For future research, a more rigorous econometric analysis can help estimate the event's impact on long-term investments and market players' expectations. Nonetheless, two general recommendations are worth highlighting in this article:

(a) Application of the present Texan anti-gouging law (or similar laws) to its spot electricity market would have posed several concerns aside from the general issues that economists have raised about such laws. The prohibition of selling at excessive prices or demanding such a price, which makes logical sense in other markets where bids are at least as high as the selling price, would be misguided for most spot electricity markets (including ERCOT), where there is a difference between the bidder and the price-setter. Moreover, the cost-focused (as opposed to value-focused) nature of anti-gouging laws risks disincentivizing demand and supply adjustments, which could result in grid collapse. Policy-makers should, therefore, consider the peculiarities of the price-formation processes in electricity markets when designing regulations to protect consumers rather than simply extending existing anti-gouging legislation to cover electricity sales.

(b) During shortages caused by such extreme events, prices on the ERCOT's spot electricity market fulfill a different role from that of other critical goods. Instead of rediscovering market equilibrium in a decentralized trial-and-error manner, administrative scarcity pricing is activated through proximate public good (system reliability) valuation via the value of the lost load. Under load shedding, overall system reliability is prioritized over electricity allocation, yet in an energy-only market, the result is the allocation of system reliability costs to spot-market buyers and load-shed consumers. It appears that complementary tools should be sought to reduce the inefficiencies produced. Whether that should ultimately entail a different market design (e.g., introducing capacity markets) is outside the scope of this article. Indeed, some approaches do not require fundamental changes. Interruptibility agreements and voluntary load shedding between utilities and consumers are some approaches that would reduce the allocative inefficiency of lower-value uses during shortages. Subsidies for mandatory weatherization, gathered from electricity taxes, may reduce the misallocation of grid reliability costs, as those costs would be borne by all electricity consumers rather than limited groups during extreme events.

While the recommendations themselves are not novel, it should be recognized that there are two separate arguments for utilizing methods complementary to scarcity pricing on electricity markets in securing system reliability. One argument (on which much academic literature has focused) is whether spot prices are high enough to attract sufficient, economically optimal levels of capacity investments to minimize scarcity events. The other, presented in this article, covers the allocation of costs through scarcity pricing and load shedding during the event, wherein some consumers bear a disproportionate cost of system reliability.

5. Conclusion

Spot electricity markets have characteristics that require an exceptional approach to price regulation during extreme events. A case study of the ERCOT's energy-only market during the 2021 winter event and analysis of price formation in such markets showcases that standard anti-gouging legislation, due to its focus on the supply side, would be counterproductive if applied to the electricity market. More importantly, the dual question of overall system reliability and efficient electricity allocation implies further challenges in applying VoLL pricing as a scarcity mechanism under shortage in a market designed for a single good. As system reliability costs were disproportionately allocated to some consumers during the event (namely, spot market purchasers and load-shed consumers) despite benefits to all consumers, approaches complementary to spot price signaling should be sought to cover system reliability costs.

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References

Baker, Colleen M., and James W. Coleman. "Paying for Energy Peaks: Learning from Texas' February 2021 Power Crisis." *Transactions: The Tennessee Journal of Business and Law*, vol. 23, 2022, pp. 463–475. Accessed at https://ir.law.utk.edu/cgi/viewcontent.cgi?article=1612&context=transactions

Berariu, Romana, et al. "Understanding the Impact of Cascade Effects of Natural Disasters on Disaster Relief Operations." *International Journal of Disaster Risk Reduction*, vol. 12, June 2015, pp. 350–356, https://doi.org/10.1016/j.ijdrr.2015.03.005.

Biggar, Darryl R, and Mohammad Reza Hesamzadeh. "Crises in Texas and Australia: Failures of Energy-Only Markets or Unforeseen Consequences of Price Caps?" *Energy Economics*, vol. 137, Sept. 2024, p. 107810, https://doi.org/10.1016/j.eneco.2024.107810.

Borenstein, Severin, et al. "The Economics of Electricity Reliability." *Journal of Economic Perspectives*, vol. 37, no. 4, 2023, pp. 181–206, https://doi.org/10.1257/jep.37.4.181.

Borreson, Jillian Marie. "Houston, We Have a Market Design Problem: Why the Legislative Response to Winter Storm Uri Does Not Yet Develop a More Efficient Market Mechanism to Ensure Reliability." *Oil and Gas, Natural Resources, and Energy Journal*, vol. 7, no. 4, Aug. 2022, pp 865 - 910 Accessed at https://digitalcommons.law.ou.edu/cgi/viewcontent.cgi?article=1359&context=onej

Botzen, W J Wouter, et al. "The Economic Impacts of Natural Disasters: A Review of Models and Empirical Studies." *Review of Environmental Economics and Policy*, vol. 13, no. 2, 2019, pp. 167–188, https://doi.org/10.1093/reep/rez004.

Busby, Joshua, et al. "Cascading Risks: Understanding the 2021 Winter Blackout in Texas." *Energy Research & Social Science*, vol. 77, July 2021, p. 102106, https://doi.org/10.1016/j.erss.2021.102106.

Cramton, Peter. "Electricity Market Design." *Oxford Review of Economic Policy*, vol. 33, no. 4, 2017, pp. 589–612, https://doi.org/10.1093/oxrep/grx041.

Electric Reliability Council of Texas. *Update to April 6, 2021 Preliminary Report on Causes of Generator Outages and Derates during the February 2021 Extreme Cold Weather Event*. 27 Apr. 2021. Accessed at https://www.ercot.com/files/docs/2021/04/28/ERCOT_Winter_Storm_Generator_Outages_By_Cause_Updated_Report_4.27.21.pdf

Friedman, Milton. *Essays in Positive Economics*. Chicago, The University Of Chicago Press, 1966.

Gorman, Will. "The Quest to Quantify the Value of Lost Load: A Critical Review of the Economics of Power Outages." *The Electricity Journal*, vol. 35, no. 8, Oct. 2022, p. 107187, https://doi.org/10.1016/j.tej.2022.107187.

Gruber, Katharina, et al. "Profitability and Investment Risk of Texan Power System Winterization." *Nature Energy*, vol. 7, 4 Apr. 2022, pp. 409–416, https://doi.org/10.1038/s41560-022-00994-y.

Hartley, Peter, et al. "The Texas Deep Freeze of February 2021: What Happened and Lessons Learned?" *Economics of Energy and Environmental Policy*, vol. 12, no. 2, 2023, https://doi.org/10.5547/2160-5890.12.2.phar.

Hayek, Friedrich A. "The Use of Knowledge in Society" *The American Economic Review*, 35, 519-530, Sep. 1945

Helveston, Max. "Regulating Economic Opportunism in Post-Disaster Markets." *North Carolina Law Review*, vol. 102, no. 3, 2024, pp. 811-864, Accessed at https://scholarship.law.unc.edu/cgi/viewcontent.cgi?article=6968&context=nclr

Hirth, Lion, et al. "Why Wind Is Not Coal: On the Economics of Electricity Generation." *The Energy Journal*, vol. 37, no. 3, 2016, pp. 1-28, https://doi.org/10.5547/01956574.37.3.lhir.

Hogan, William W. "Electricity Scarcity Pricing through Operating Reserves." *Economics of Energy & Environmental Policy*, vol. 2, no. 2, 2013, pp. 65-86, https://doi.org/10.5547/2160-5890.2.2.4.

Hurlbut, David, et al. "Protecting the Market from 'Hockey Stick' Pricing: How the Public Utility Commission of Texas Is Dealing with Potential Price Gouging." *The Electricity Journal*, vol. 17, no. 3, Apr. 2004, pp. 26–33, https://doi.org/10.1016/j.tej.2004.03.001.

Jaffe, Adam B., and Frank A. Felder. "Should Electricity Markets Have a Capacity Requirement? If So, How Should It Be Priced?" *The Electricity Journal*, vol. 9, no. 10, Dec. 1996, pp. 52–60, https://doi.org/10.1016/s1040-6190(96)80157-6.

Joskow, Paul, and Jean Tirole. "Reliability and Competitive Electricity Markets." *The RAND Journal of Economics*, vol. 38, no. 1, Mar. 2007, pp. 60–84, https://doi.org/10.1111/j.1756-2171.2007.tb00044.x.

Levin, Todd, et al. "Extreme Weather and Electricity Markets: Key Lessons from the February 2021 Texas Crisis." *Joule*, vol. 6, no. 1, Jan. 2022, pp. 1–7, https://doi.org/10.1016/j.joule.2021.12.015.

Littlechild, Stephen, and Lynne Kiesling. "Hayek and the Texas Blackout." *The Electricity Journal*, vol. 34, no. 6, July 2021, p. 106969, https://doi.org/10.1016/j.tej.2021.106969.

Lo Prete, Chiara, and Seth Blumsack. "Enhancing the Reliability of Bulk Power Systems against the Threat of Extreme Weather: Lessons from the 2021 Texas Electricity Crisis." *Economics of Energy & Environmental Policy*, vol. 12, no. 2, 2023, https://doi.org/10.5547/2160-5890.12.2.clop.

Madden, Connor. "The ERCOT Market's Cap and the Power Grid's Long Winter's Nap: Recommended Improvements to Texas's System-Wide Price-Capping Methodology." *Texas Law Review*, vol. 101, no. 3, 2023, pp. 684-706, Accessed at https://texaslawreview.org/the-ercot-markets-cap-and-the-power-grids-long-winters-nap-recommended-improvements-to-texass-system-wide-price-capping-methodology

Mallapragada, Dharik S, et al. "Electricity Pricing Challenges in Future Renewables-Dominant Power Systems." *Energy Economics*, vol. 126, Oct. 2023, p. 106981, https://doi.org/10.1016/j.eneco.2023.106981.

Mays, Jacob, et al. "Private Risk and Social Resilience in Liberalized Electricity Markets." *Joule*, vol. 6, no. 2, 16 Feb. 2022, pp. 369–380, https://doi.org/10.1016/j.joule.2022.01.004.

Michelfelder, Richard A., and Eugene A. Pilotte. "Climate Change, Extreme Winter Weather and Electricity Production Costs." *The Electricity Journal*, vol. 35, no. 3, Apr. 2022, p. 107093, https://doi.org/10.1016/j.tej.2022.107093.

Ovaere, Marten, et al. "How Detailed Value of Lost Load Data Impact Power System Reliability Decisions." *Energy Policy*, vol. 132, Sept. 2019, pp. 1064–1075, https://doi.org/10.1016/j.enpol.2019.06.058.

Panwar, Vikrant, and Subir Sen. "Economic Impact of Natural Disasters: An Empirical Re-Examination." *Margin: The Journal of Applied Economic Research*, vol. 13, no. 1, 2019, pp. 109–139, https://doi.org/10.1177/0973801018800087.

Papavasiliou, Anthony. "Scarcity Pricing and the Missing European Market for Real-Time Reserve Capacity." *The Electricity Journal*, vol. 33, no. 10, Dec. 2020, p. 106863, https://doi.org/10.1016/j.tej.2020.106863.

Petitet, Marie, et al. "Making Electricity Capacity Markets Resilient to Extreme Weather Events." *Economics of Energy & Environmental Policy*, vol. 12, no. 2, 2023, https://doi.org/10.5547/2160-5890.12.2.mpet.

Praktiknjo, Aaron J. "The Value of Lost Load for Sectoral Load Shedding Measures: The German Case with 51 Sectors." *Energies*, vol. 9, no. 2, 19 Feb. 2016, p. 116, https://doi.org/10.3390/en9020116.

Praktiknjo, Aaron J. "Stated Preferences Based Estimation of Power Interruption Costs in Private Households: An Example from Germany." *Energy*, vol. 76, Nov. 2014, pp. 82–90, https://doi.org/10.1016/j.energy.2014.03.089.

Potomac Economics. *2021 State of the Market Report for the ERCOT Electricity Markets*. May 2022. Accessed at https://www.potomaceconomics.com/wp-content/uploads/2022/05/2021-State-of-the-Market-Report.pdf

Public Utility Commission of Texas. PUC Project no. 51617: Order Directing ERCOT to Take Action and Granting Exception to Commission Rules. 15 Feb. 2021, www.ercot.com/files/docs/2021/02/16/51617WinterERCOTOrder.pdf.

Rahman, K. M. Jawadur, et al. "Largest Blackouts around the World: Trends and Data Analyses." 2016 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE) https://doi.org/10.1109/WIECON-ECE.2016.8009108

Schröder, Thomas, and Wilhelm Kuckshinrichs. "Value of Lost Load: An Efficient Economic Indicator for Power Supply Security? A Literature Review." *Frontiers in Energy Research*, vol. 3, 24 Dec. 2015, https://doi.org/10.3389/fenrg.2015.00055.

Sirin, Selahattin Murat, et al. "Market Failure or Politics? Understanding the Motives behind Regulatory Actions to Address Surging Electricity Prices." *Energy Policy*, vol. 180, Sep. 2023, p. 113647, https://doi.org/10.1016/j.enpol.2023.113647.

Sirin, Selahattin Murat, and Ibrahim Erten. "Price Spikes, Temporary Price Caps, and Welfare Effects of Regulatory Interventions on Wholesale Electricity Markets." *Energy Policy*, vol. 163, Apr. 2022, p. 112816, https://doi.org/10.1016/j.enpol.2022.112816.

Skarbek, David. "Market Failure and Natural Disasters: A Reexamination of Anti-Gouging Laws." *Public Contract Law Journal*, *37*(4), 2008, pp. 771–780. https://www.jstor.org/stable/25755687

Supreme Court of Texas. *Public Utility Commission of Texas v. Luminant Energy Company LLC*. Opinion delivered on 14 June 2024. Accessed at https://www.txcourts.gov/media/1458729/230231.pdf.

Varawala, Lamia, et al. "A Pricing Mechanism to Jointly Mitigate Market Power and Environmental Externalities in Electricity Markets." *Energy Economics*, vol. 121, May 2023, p. 106646, https://doi.org/10.1016/j.eneco.2023.106646.

Wright, Jesse T., et al. "Price Gouging in a Hurricane: Do Free Market Forces Circumvent Price Controls?" *Journal of Business & Economics Research (JBER)*, vol. 16, no. 2, 1 Nov. 2019, pp. 19–30, https://doi.org/10.19030/jber.v16i2.10319.